



# **Is there an optimal ENSO pattern that enhances large-scale atmospheric processes conducive to tornado outbreaks in the U.S?**

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## **Outline**

- Motivation and Background**
- Trans-Niño and U.S. Tornado Activity**
- Trans-Niño and Historical Super Tornado outbreaks**
- ENSO Transitions in Boreal Spring**
- Summary and Discussions**



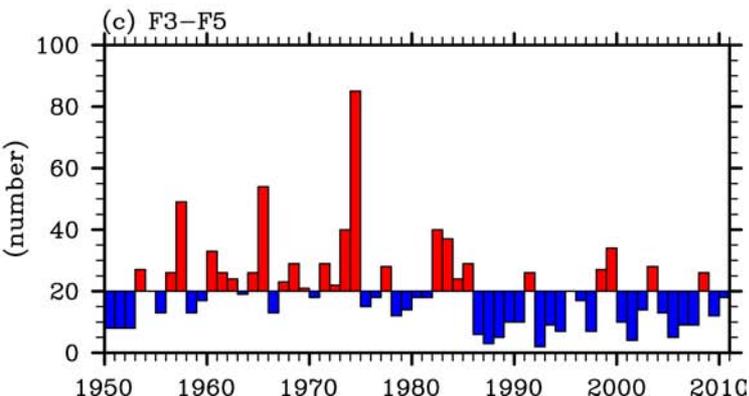
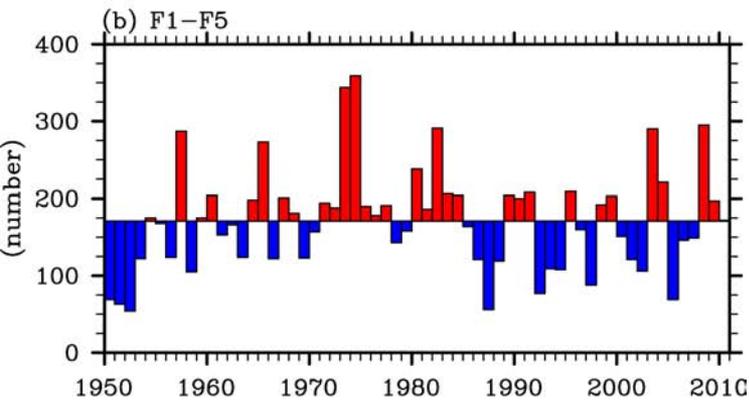
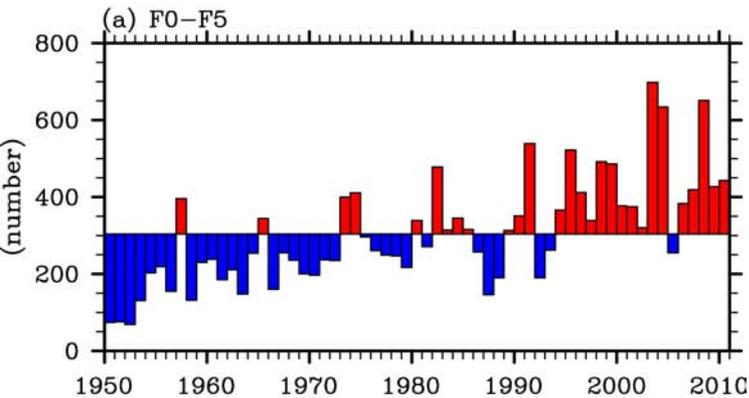
**April 27, 2011 Tuscaloosa, Alabama**

**April 29, 2011 Tuscaloosa, Alabama**

- In April and May of 2011, a record breaking 1,084 tornadoes and 541 tornado-related fatalities were confirmed in the U.S.
- 2011 (541) was one of the four deadliest tornado years in the U.S. history along with 1925 (794), 1936 (552) and 1917 (551).
- Questions were raised as to whether the extreme tornadoes outbreaks in 2011 could be linked to long-term climate variability.

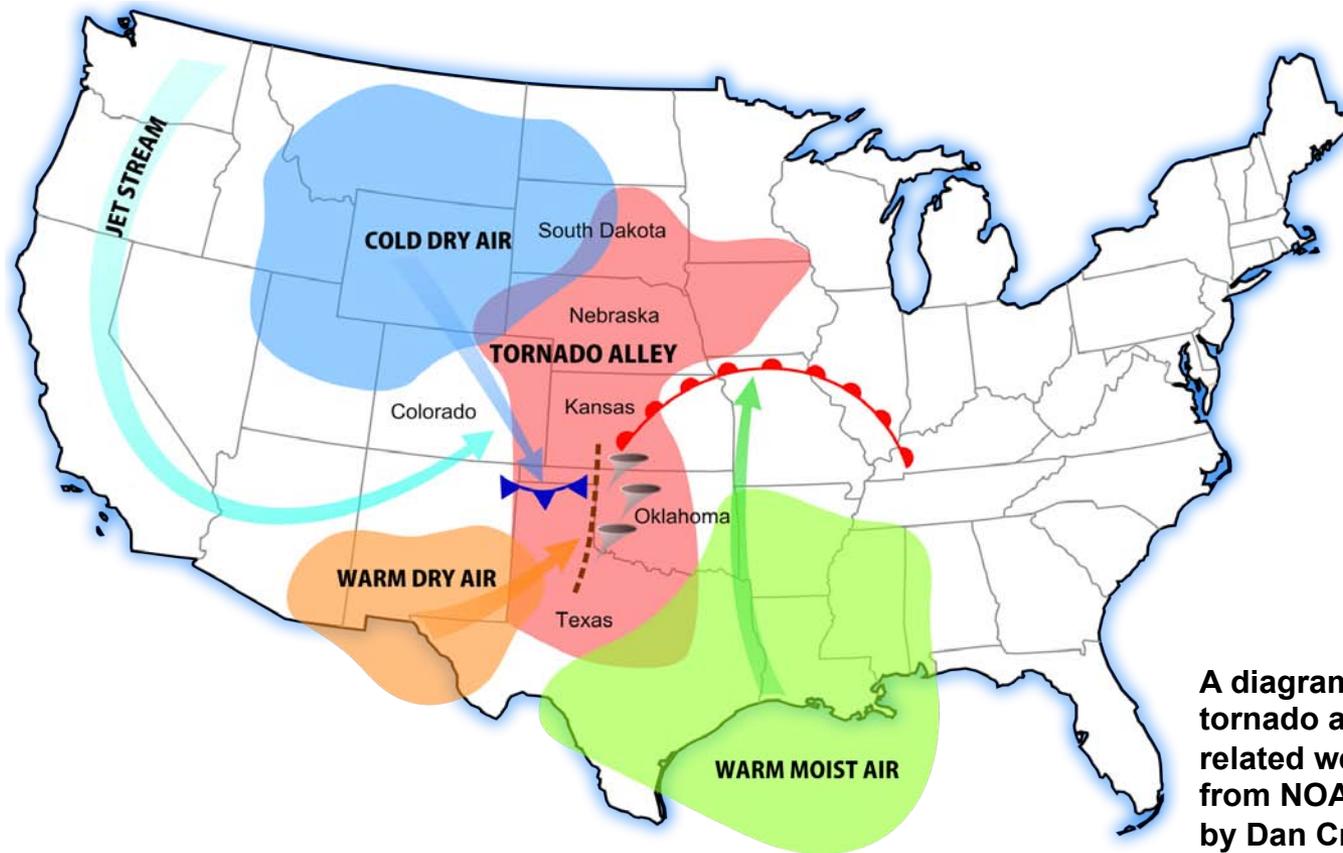
# Is U.S. Tornado Activity Increasing?

SWD: Number of U.S. Tornadoes (APR–MAY)



- The number of total U.S. tornadoes (F0–F5) during the most active tornado months of April and May (AM) has been steadily increasing since 1950.
- However, tornado database, especially in earlier periods, has many issues.
- Once F0 tornadoes are removed, the positive trend disappears.
- Intense and long-lived tornadoes are much more likely to be detected and reported even before a national network of Doppler radar was built in the 1990s.
- Here, we use the number of intense U.S. tornadoes (F3–F5) in AM as the primary diagnostic index in this study.
- Intense tornado-days is also used as an index.

# Environmental factors for U.S. tornadoes



A diagram of the location of tornado alley and the related weather systems from NOAA SPC (Art work by Dan Craggs)

- In the central U.S. east of the Rocky Mountains, cold and dry upper-level air from the high-latitudes often converges with warm and moist lower-level air coming from the Gulf of Mexico.
- Due to this large-scale differential advection, a conditionally unstable atmosphere with high CAPE is formed. The associated lower-level vertical shear further provides a favorable environment to form an intense rotating thunderstorm known as a supercell.



# U.S. Tornado Activity and Climate Indices

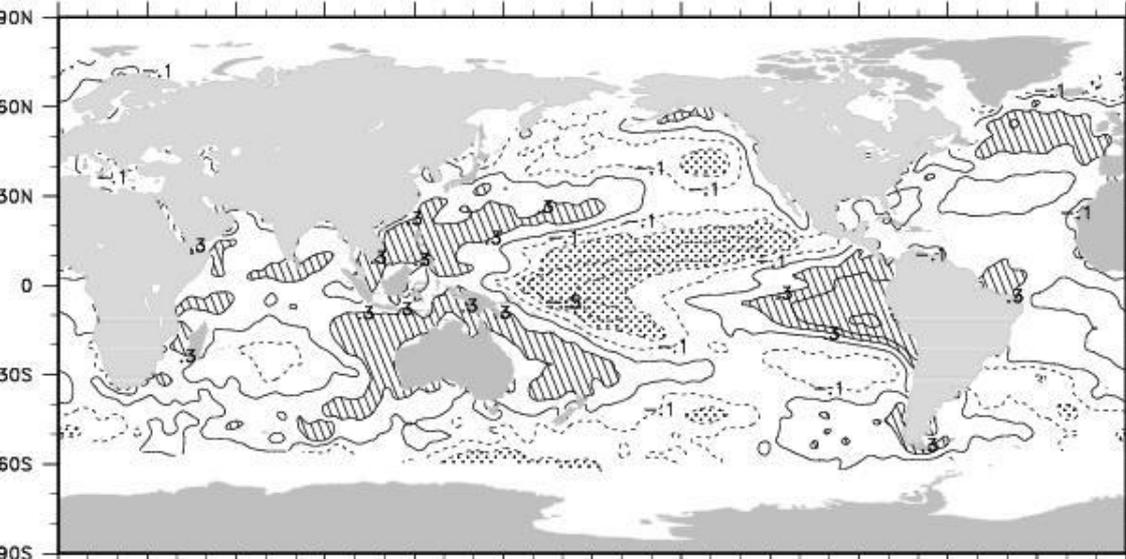


Index	DJF	FMA	AM
GoM-to-U.S. moisture transport	0.12 ( 0.09)	0.20 ( 0.10)	<b>0.44 ( 0.34)</b>
Lower-Level vertical wind shear	0.12 ( 0.09)	0.20 ( 0.12)	<b>0.44 ( 0.35)</b>
GoM SST	0.15 ( 0.15)	0.21 ( 0.16)	0.20 ( 0.19)
Niño-4	-0.22 (-0.19)	-0.20 (-0.18)	-0.19 (-0.18)
Niño-3.4	-0.13 (-0.11)	-0.13 (-0.12)	-0.11 (-0.11)
Niño-1+2	0.02 ( 0.03)	0.11 ( 0.11)	0.15 ( 0.13)
TNI	<b>0.28 ( 0.26)</b>	<b>0.29 ( 0.28)</b>	<b>0.33 ( 0.29)</b>
PNA	-0.05 (-0.02)	-0.10 (-0.06)	-0.20 (-0.16)
PDO	-0.12 (-0.09)	-0.10 (-0.11)	-0.14 (-0.20)
NAO	-0.01 (-0.07)	-0.10 (-0.14)	-0.18 (-0.18)

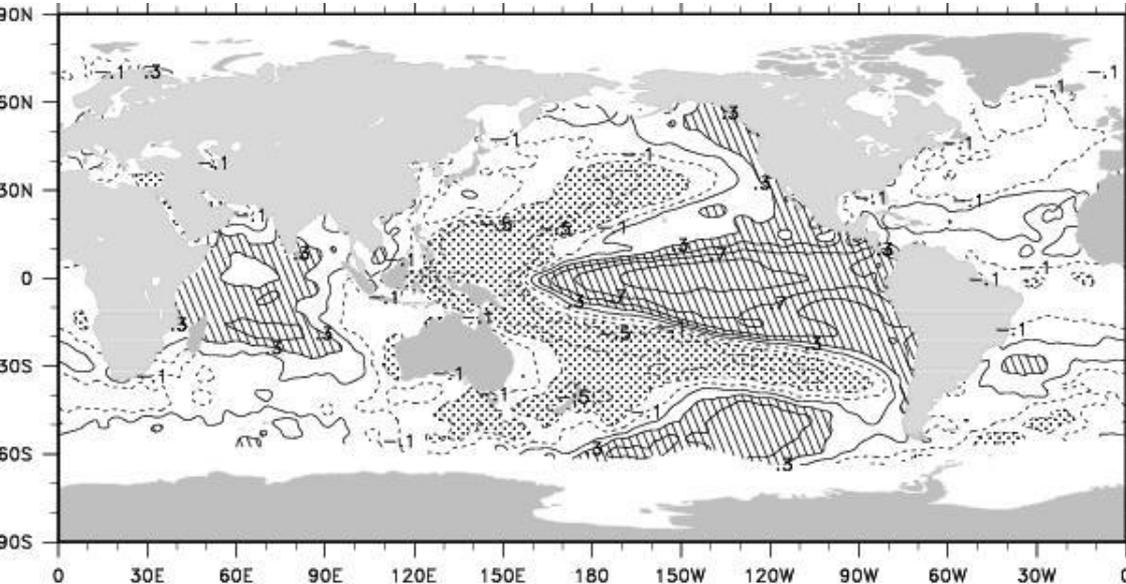
- Correlation coefficients of various long-term climate patterns with the number of intense tornadoes (tornado-days)
- Niño-3.4 has a very weak correlation with U.S. Tornado activity, consistent with previous studies.
- Niño-4 is negatively correlated, while Niño-1+2 is positively correlated.
- U.S. tornado activity is more strongly correlated with Trans-Niño (TNI) than any other climate pattern.

# What is Trans-Niño (TNI)?

Correlation between TNI and SST anomalies during 1977-2000



Correlation between Niño-3.4 and SST anomalies during 1977-2000



- TNI is defined as the difference in normalized SST anomalies between the Niño-1+2 and Niño-4 regions [Trenberth and Stepaniak, 2001].
- It represents the evolution of ENSO during its onset and decaying phases, which frequently occur in boreal spring.
- Why is the number of intense U.S. tornadoes in AM significantly correlated with the TNI index, but not with conventional ENSO?



# Trans-Niño and U.S. Tornado Activity

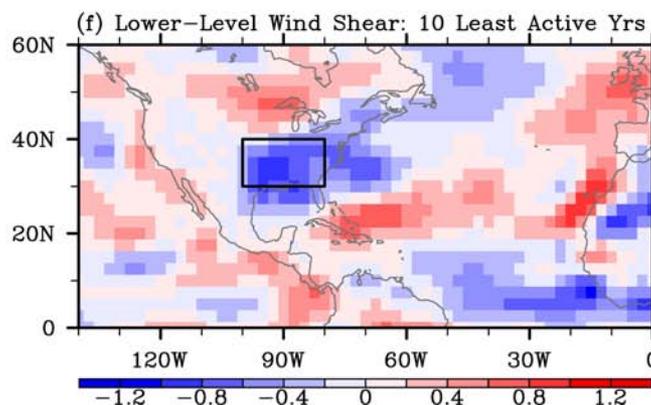
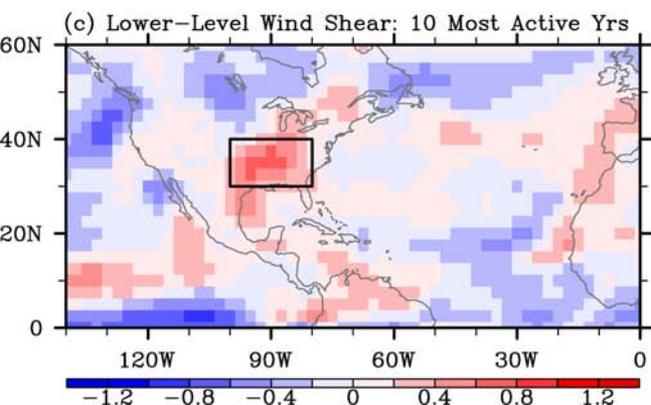
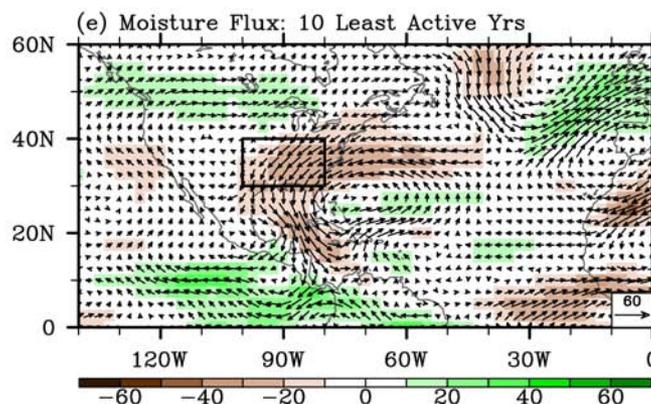
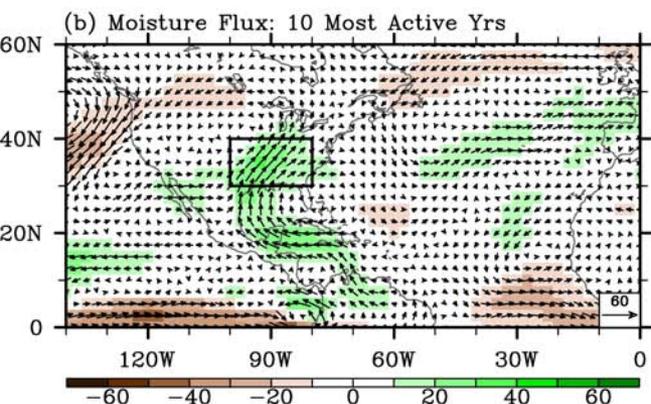
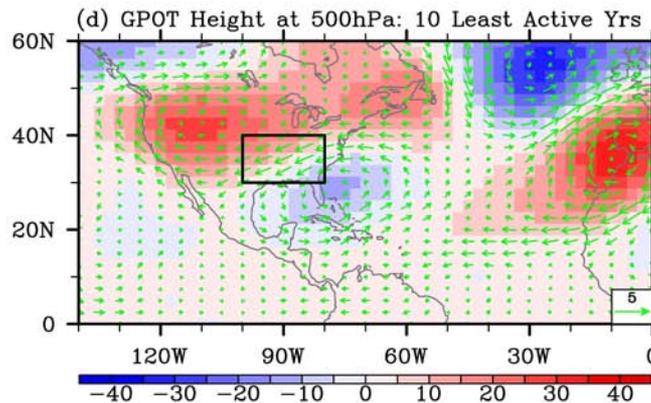
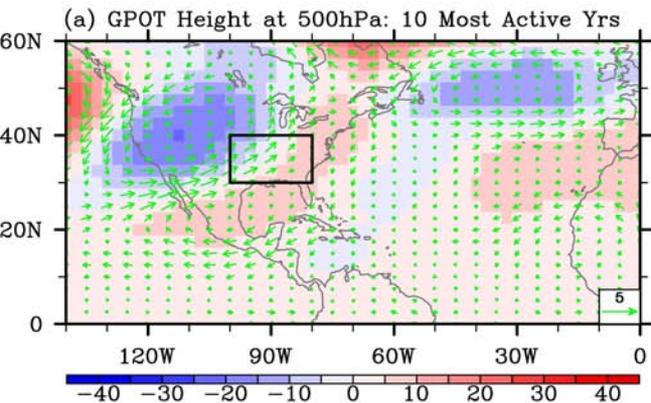


Ranking	Year	ENSO phase in spring	TNI index (detrended)
1	1974	La Niña persists	1.30 ( 1.48)
2	1965	La Niña transitions to El Niño	1.39 ( 1.54)
3	1957	La Niña transitions to El Niño	0.57 ( 0.69)
4	1982	El Niño develops	-1.11 (-0.89)
5	1973	El Niño transitions to La Niña	-0.42 (-0.24)
6	1999	La Niña persists	0.47 ( 0.75)
7	1983	El Niño decays	1.86 ( 2.08)
8	2003	El Niño decays	-1.24 (-0.94)
9	2008	La Niña decays	1.41 ( 1.73)
10	1998	El Niño transitions to La Niña	1.69 ( 1.97)

- However, correlation analysis may be misleading.
- Top 10 extreme tornado outbreak years during 1950-2010 are listed in the table.
- 7 out of the top 10 extreme tornado years are identified with positive phase (within the upper quartile) TNI.
- The top 3 years (1974, 1965 and 1957) are also identified with positive phase (within the upper quartile) TNI.
- The 10 least active tornado years are largely neutral TNI years (not shown).

# Key Atmos. Conditions for U.S. Tornado Outbreaks

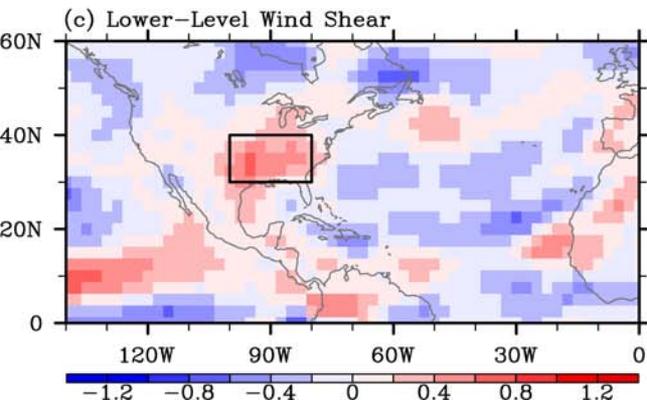
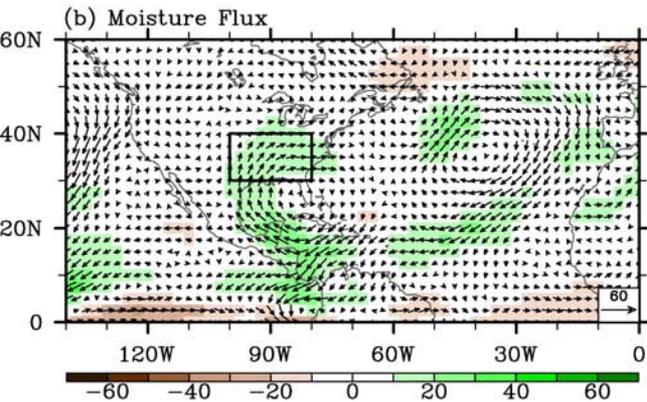
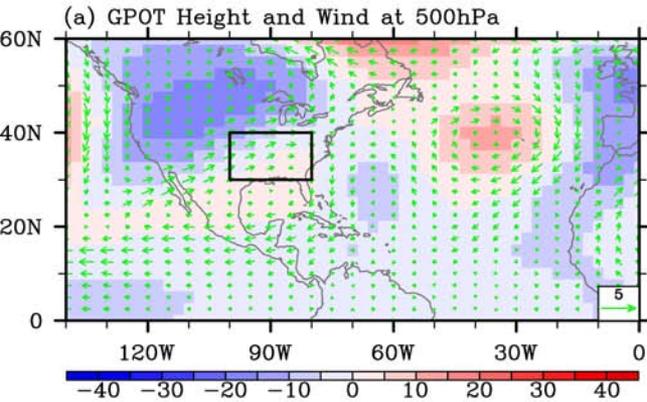
NCEP-NCAR Reanalysis: Key Atmospheric Conditions during Active and Inactive Years (APR-MAY)



- Anomalous upper-level cyclone over the North America brings more cold and dry upper-level air to the east of the Rockies.
- Increased GoM-to-U.S. lower-level wind (i.e., GPLLJ) and associated moisture transport.
- Enhanced large-scale differential advection leads to increased CAPE and vertical wind shear east of the Rockies.

# Trans-Niño and U.S. Tornado Activity

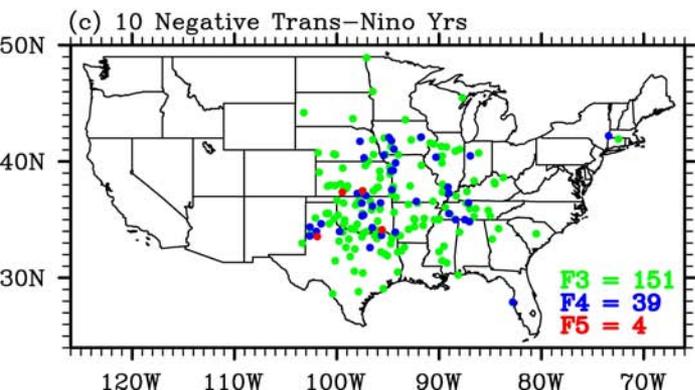
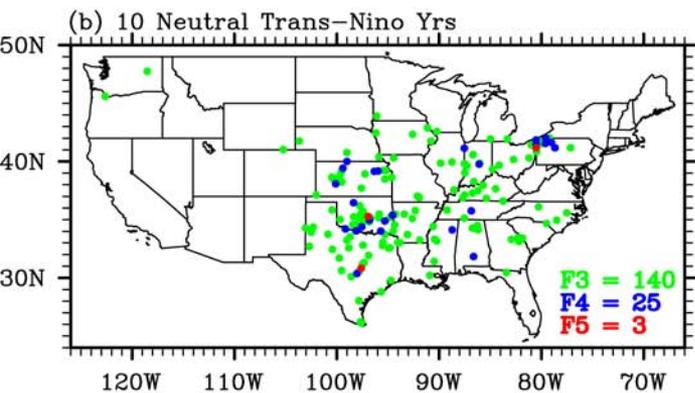
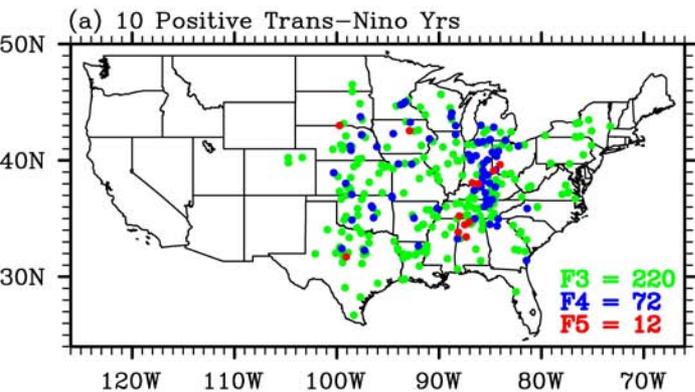
NCEP–NCAR Reanalysis: Pos. TNI Years (APR–MAY)



- Key atmospheric conditions for the top 10 positive TNI years are shown.
- Anomalous upper-level cyclone over the North America brings more cold and dry upper-level air to the east of the Rockies.
- Increased GoM-to-U.S. lower-level wind (i.e., GPLLJ) and associated moisture transport.
- Enhanced large-scale differential advection leads to increased CAPE and vertical wind shear east of the Rockies.
- All these conditions are consistent with those for the top 10 extreme tornado outbreak years.

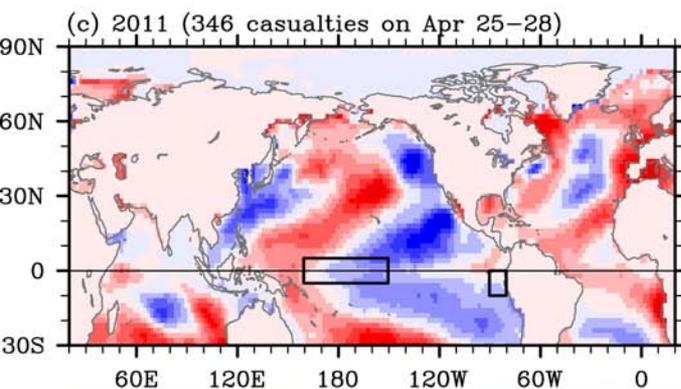
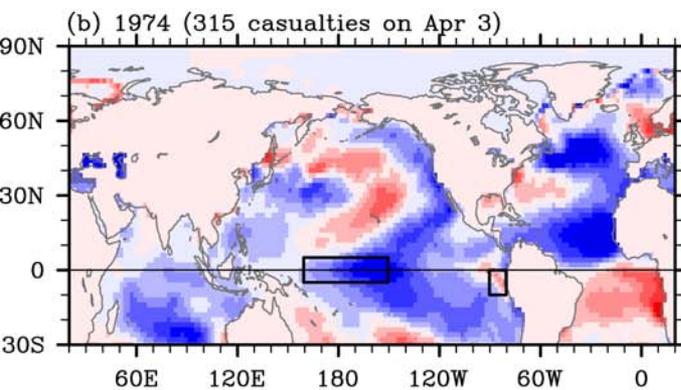
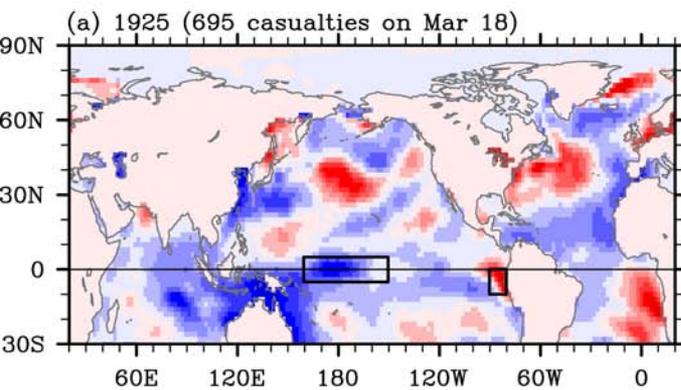
# Trans-Niño and U.S. Tornado Activity

SWD: Incidents of Intense (F3–F5) U.S. Tornadoes during 1950–2010 (APR–MAY)



- Incidents of intense (F3-F5) tornadoes for 10 positive, 10 neutral and 10 negative Trans-Niño years during 1950-2010 are shown.
- Number of intense tornadoes is increased from 168 during the 10 neutral TNI years to 304 during the 10 positive TNI years (It is almost doubled).
- During positive TNI years, violent (F4-F5) tornadoes are increased over the Ohio river valley.
- During negative TNI years, number of intense tornadoes is not increased.

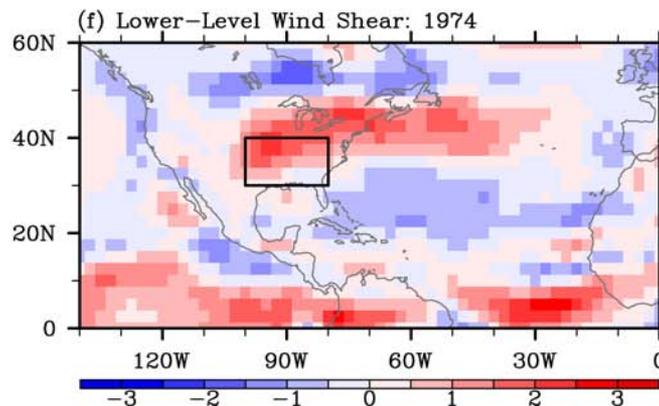
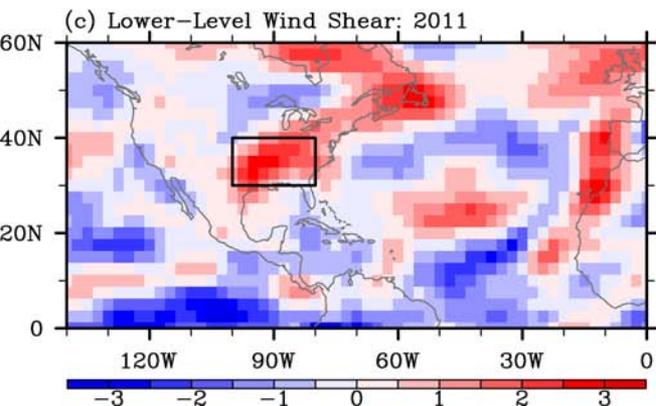
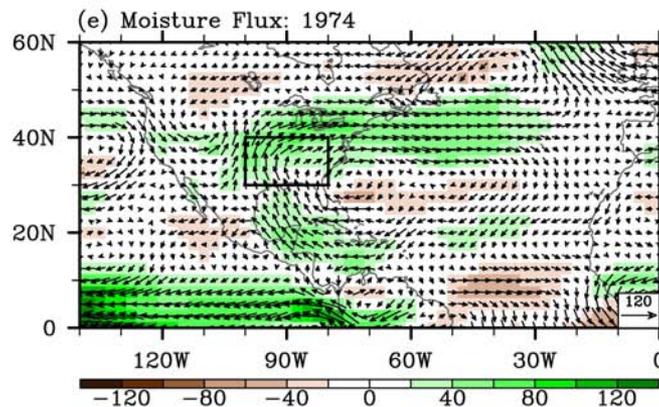
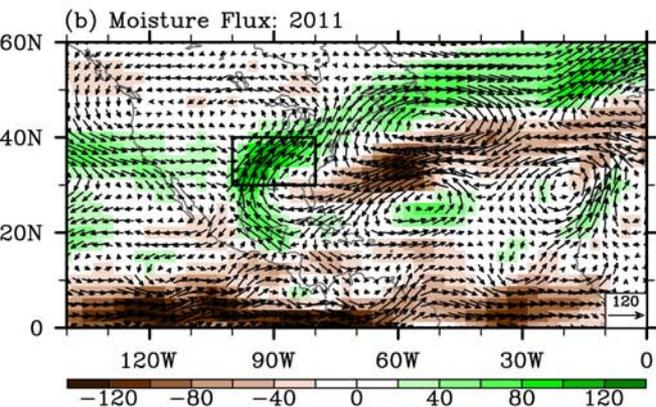
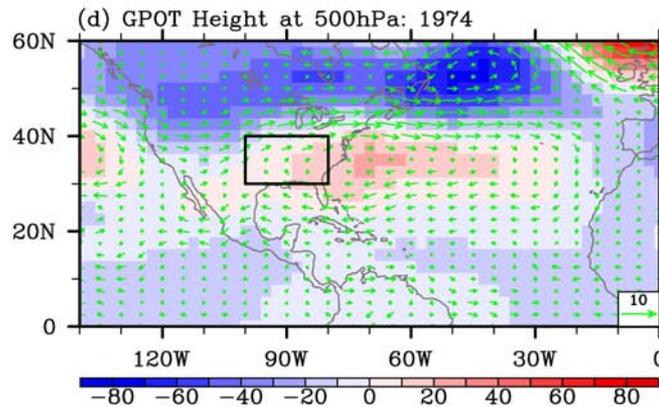
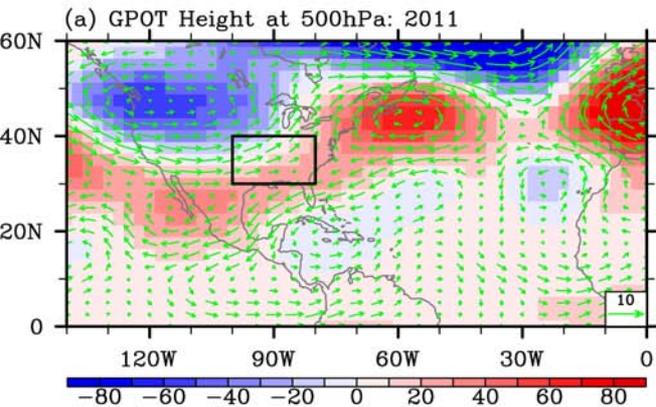
ERSST3: SST Anomalies (APR–MAY)



- **Tri-state (Missouri, Illinois and Indiana) tornado of March 18, 1925 is the deadliest tornado outbreak event in the U.S. history (695 deaths).**
- **Super tornado outbreak on April 3, 1974 resulted in 315 deaths.**
- **April 25-28, 2011 is the 2nd deadliest tornado outbreak event (346 deaths).**
- **1936 (552) and 1917 (551) are the 2nd and 3rd deadliest tornado years.**
- **All five of these historic tornado outbreak years were positive Trans-Niño years.**
- **April & March of 1917 is marked as the strongest TNI during the period of 1854 – 2011 (not shown).**

# Trans-Niño and Historical U.S. Tornado Outbreaks

NCEP-NCAR Reanalysis: Key Atmospheric Conditions during Historical Outbreak Years (APR-MAY)



- All three conditions are consistent with those for the 10 positive Trans-Niño years.
- This means that the positive Trans-Niño condition during these historical tornado outbreak years are not just coincident.
- Therefore, it is likely that the positive Trans-Niño condition have contributed to these historical tornado outbreak events.



## Summary and Discussions



- **Observations and reanalysis products are used to show that a positive phase of the Trans-Niño is linked to U.S. tornado outbreaks.**
- **The TNI-U.S. tornado link is due to the enhanced large-scale differential advection during a positive phase of the Trans-Niño**
  - 1) anomalous upper-level cyclone over the North America;**
  - 2) increased GoM-to-U.S. moisture transport;**
  - 3) increased lower-level vertical wind shear east of the Rockies.**
- **Lee et al. [2013, JCL in-press] used model experiments to explore the potential mechanisms for the link between Trans-Niño and U.S. tornado activity.**
- **Positive Trans-Niño frequently occurs during either the onset phase of El Niño or the decay phase of La Niña (not shown).**

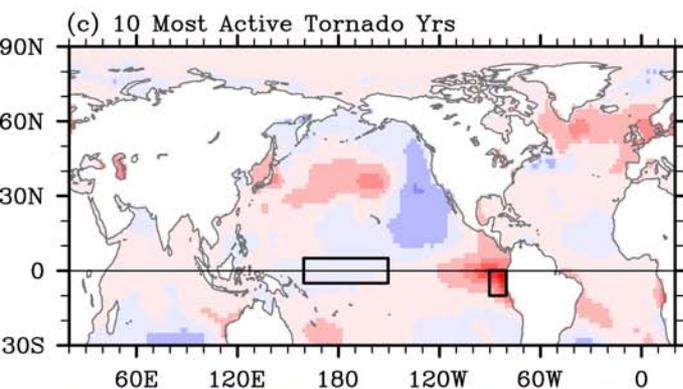
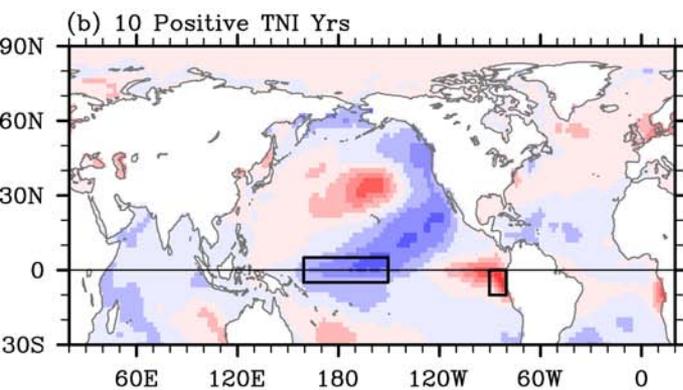
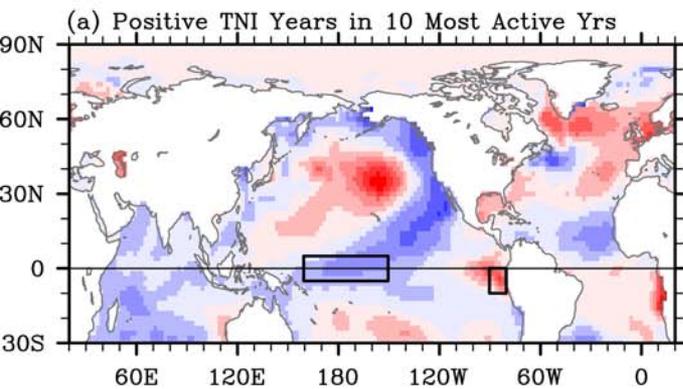


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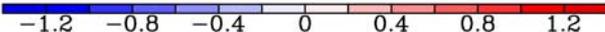


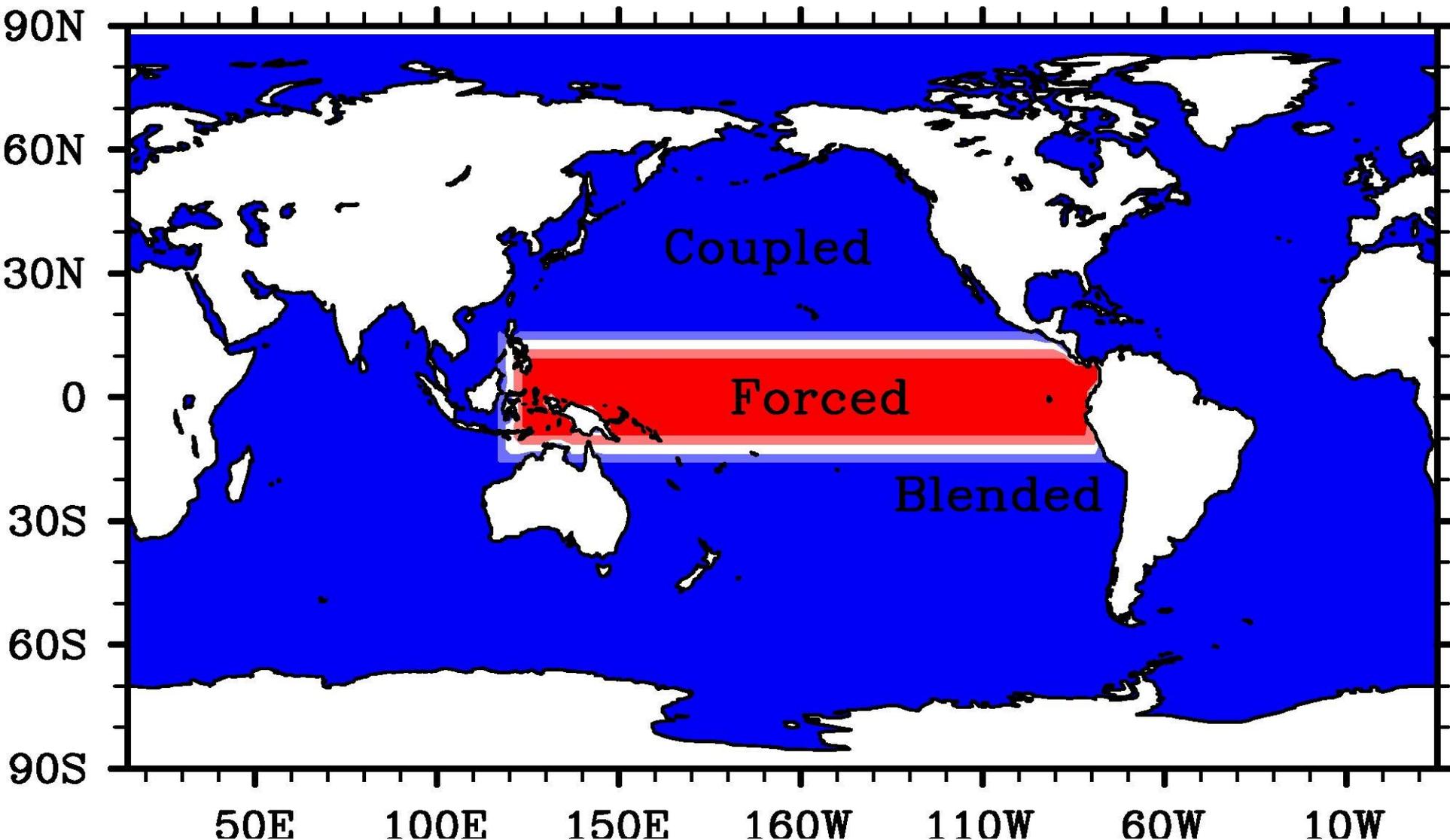
# Trans-Niño and U.S. Tornado Activity

ERSST3: SST Anomalies (APR–MAY)



- SST anomalies for 5 positive TNI years identified among the 10 most active tornado years are shown in the upper panel.
- SST anomalies for 10 positive TNI years and for the 10 most active tornado years are shown in the middle and upper panels.
- Positive Trans-Niño occurs when normalized SST anomalies are larger in Niño-1+2 than in Niño-4 region [Trenberth and Stepaniak 2001].
- Therefore, neutral Niño-4 with positive Niño-1+2 and neutral Niño-1+2 with negative Niño-4 are also qualified as positive TNI conditions.



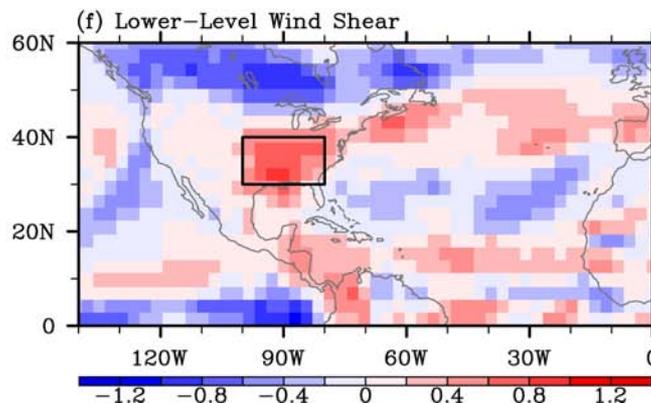
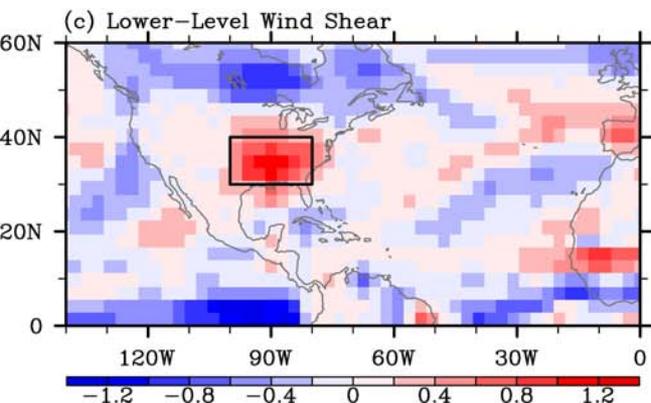
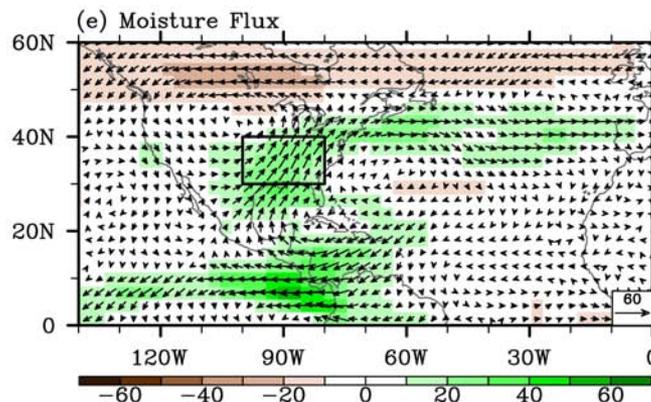
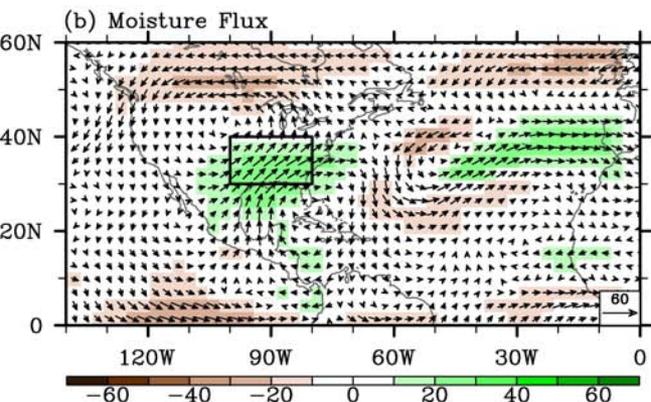
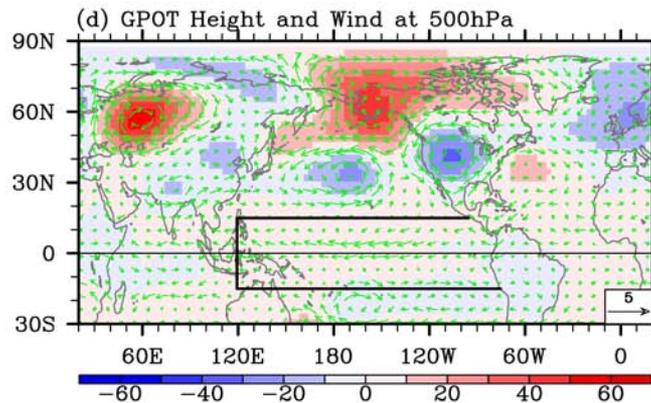
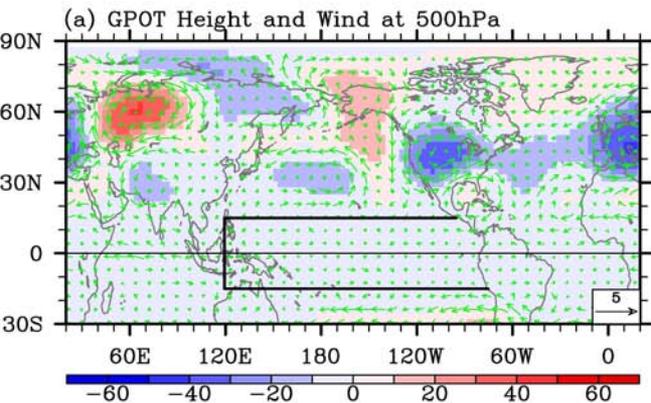


- The same methodology was previously used in Lee et al. [2008] for studying ENSO teleconnection to the tropical North Atlantic region.

# Model Experiments (CAM3-SOM)

CAM3: EXP\_TN1 – EXP\_CLM (APR–MAY)

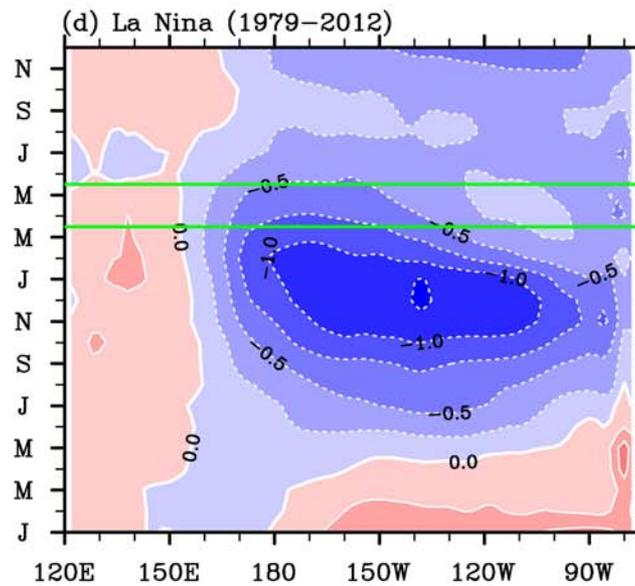
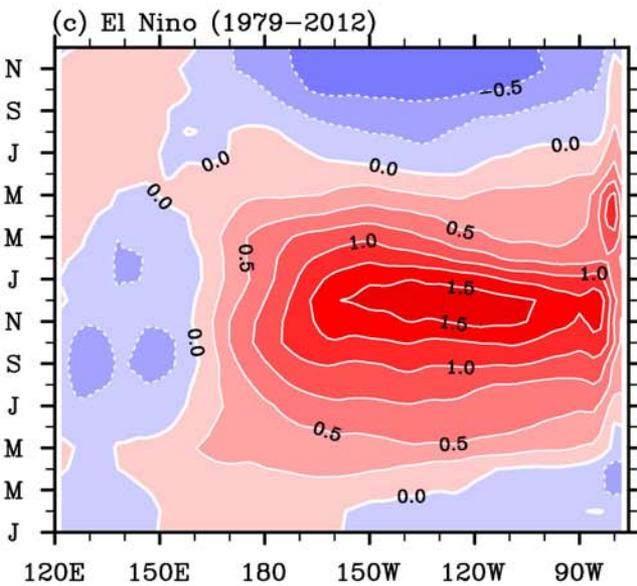
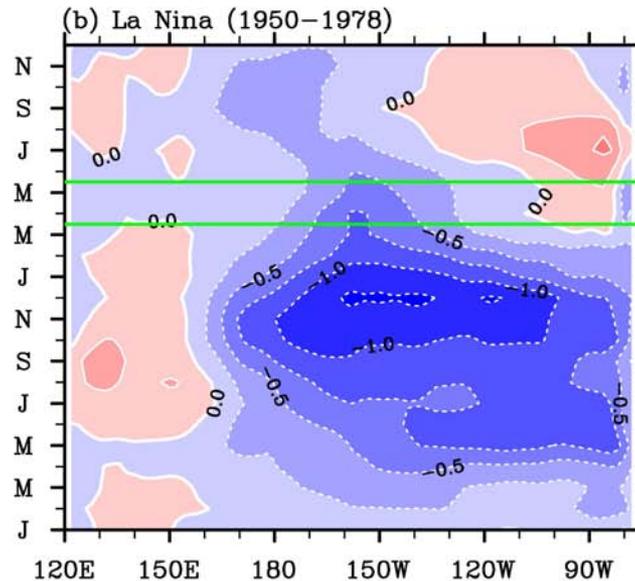
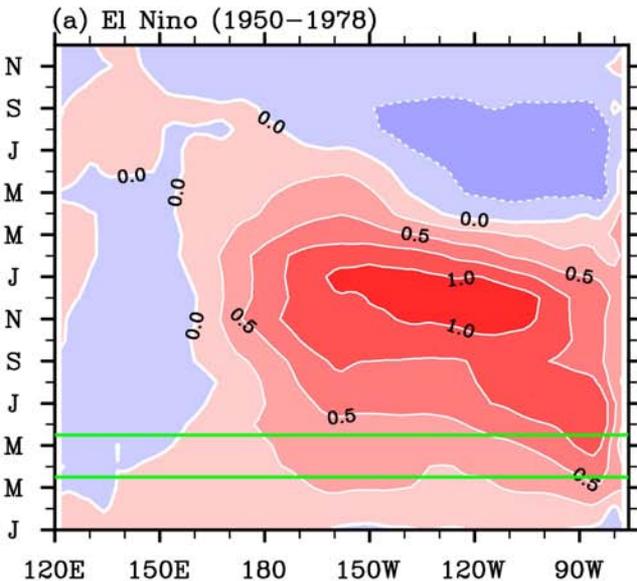
CAM3: EXP\_TN2 – EXP\_CLM (APR–MAY)



- Results from EXP\_TN1 and EXP\_TN2 are shown.
- EXP\_TN1: Tropical Pacific SSTs are prescribed with the composite of 10 positive TNI years.
- EXP\_TN2: Tropical Pacific SSTs are prescribed with the composite of 10 most active years.
- All three conditions are favorable for increased U.S. tornado activity.

# ENSO Transitions in Boreal Spring

ERSST3: Composite of ENSO SST anomalies

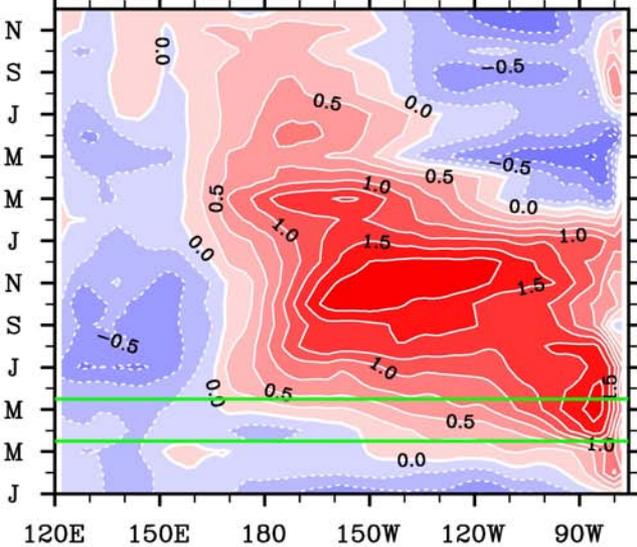


- Prior to 1976/77 climate shift, a positive Trans-Niño could occur during the onset of an El Niño and the decay of a La Niña.
- After 1976/77, a positive Trans-Niño occurs only during the decay phase of a La Niña.
- Reproduced from McPhaden and Zhang (2009)

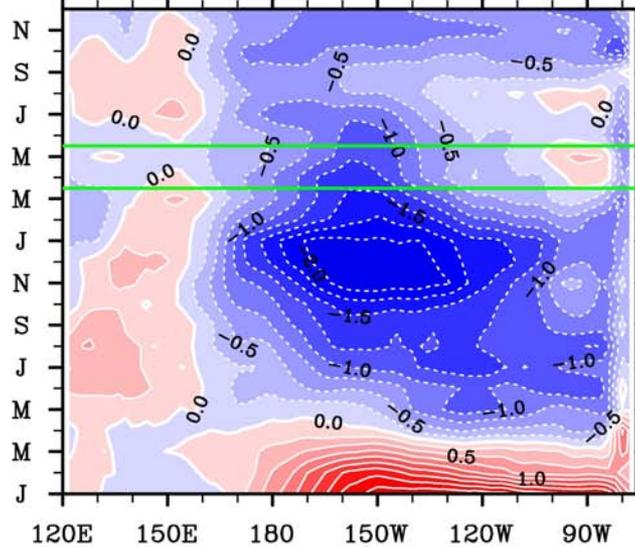
# ENSO Transitions & U.S. Tornado Outbreaks

ERSST3: ENSO transitions during U.S. tornado outbreak years

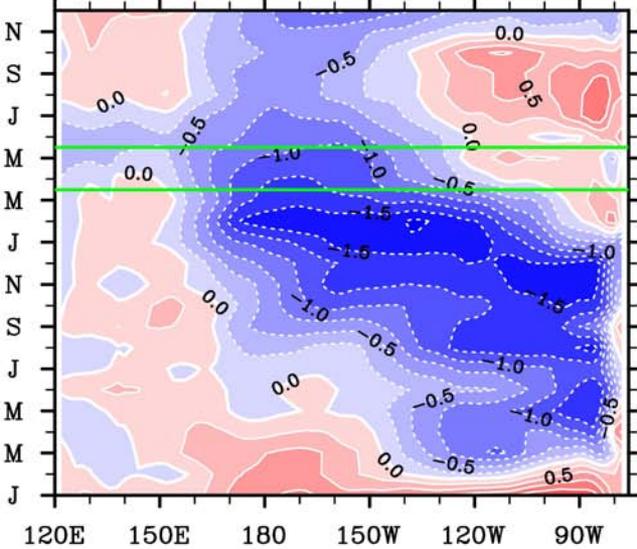
(a) 1965 Outbreak



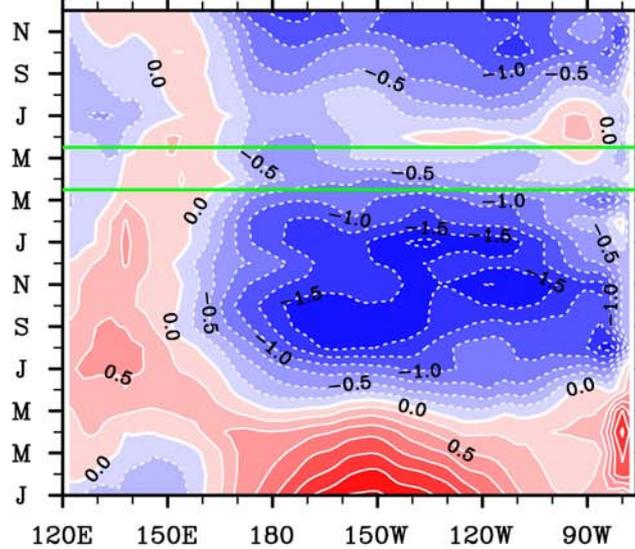
(b) 1974 Outbreak



(c) 2008 Outbreak



(d) 2011 Outbreak



- **1965 outbreak occurred during the onset phase of an El Niño .**
- **After 1975/76, however, the onset phase of El Niño is rarely associated with U.S. tornado outbreaks.**
- **Many U.S. tornado outbreak years are linked to the decay phase of La Niña (ex: 1974, 1999, 2008 and 2011).**



# What is Fujita Scale?



Damage f scale	Little Damage		Minor Damage		Roof Gone	Walls Collapse	Blown Down	Blown Away
	f0	f1	f2	f3	f4	f5		
Windspeed F scale	17 m/s	32	50	70	92	116	142	
	40 mph	73	113	158	207	261	319	
To convert f scale into F scale, add the appropriate number								
Weak Outbuilding	-3	f3	f4	f5	f5	f5	f5	
Strong Outbuilding	-2	f2	f3	f4	f5	f5	f5	
Weak Framehouse	-1	f1	f2	f3	f4	f5	f5	
Strong Framehouse	0	F0	F1	F2	F3	F4	F5	
Brick Structure	+1	-	f0	f1	f2	f3	f4	
Concrete Building	+2	-	-	f0	f1	f2	f3	

Fig. 2.4-1 The Fujita tornado scale (F scale) pegged to damage-causing windspeeds. The extent of damage expressed by the damage scale (f scale) varies with both windspeed and the strength of structures.



## Discussions - continued



- **Lee et al. [2013, JCL in-press] explored the potential mechanisms for the link between Trans-Niño and U.S. tornado activity**
- **The highlight of Lee et al. [2013] is that background atmospheric structure in spring makes the central tropical Pacific as an ideal spot to force a robust teleconnection pattern that enhances the differential advection east of the Rockies.**
- **TNI-based seasonal hindcast for 1950-2010:**
  - 1) **15 tornado outbreak warnings should be issued.**
  - 2) **7 tornado outbreaks occurred and 8 were false alarm.**
  - 3) **3 tornado outbreaks missed.**
  - 4) **7 out of 10 tornado outbreaks were potentially predictable.**
- **List of things to do**
  - 1) **Better understanding of the TNI - differential advection linkage**
  - 2) **Seasonal predictability of TNI and associated teleconnection**
  - 4) **We need clean long-term tornado data (both obs- and proxy-based)**